AC/DC System Dynamics Under AC Power System Faulted Conditions

A sensitivity on DC Voltage Control parameters

Mario Ndreko
Delft University of Technology, Faculty of EEMCS,
Intelligent Electrical Power Grids, Delft, the Netherlands
m.ndreko@tudelft.nl
Contents

• Background
• Model of the VSC-Based MTDC grid
• Control of the DC voltage in the MTDC grid
• Test system and results
• Conclusions
Problem Background

• What is the **combined** AC-DC system dynamic response under AC power system faulted conditions?

• How does **DC voltage control parameters** influence the AC-DC system dynamics?

• What is the influence of the **DC grid topology** on these interactions between the AC and the DC system?
VSC-HVDC System

- Outer Controllers
- Inner Controllers
- PWM
- Switching modules
Model of the MTDC Grid

• Detailed switch model includes small time constants which involves high computational costs
• Simplifications are necessary when modeling AC and DC systems for stability studies
• The models should be simple enough for system stability studies but should not neglect the DC circuit dynamics
Model of the MTDC Grid

Simplified model of the converter: Quasi steady state model

• Assuming an infinite band width of the inner controller we neglect the inner controller dynamics

• The active and re-active current references as given by the outer controller are directly used in the dq→xy transformation

• The output current is also limited by means of control

• AC and DC side are coupled by the relation of the power balance
Model of the MTDC Grid

Model of the DC cables

Newton Raphson DC grid system power flow for initialization of state space model (Loss-less converter)

\[
\frac{dx}{dt} = Ax + Bu
\]

\[
x = \begin{bmatrix} U^1_{dc} & U^2_{dc} & \cdots & U^n_{dc} & I^1_{br} & I^2_{br} & \cdots & I^m_{br} \end{bmatrix}^T_{1x(m+n)}
\]

\[
u = \begin{bmatrix} I^1_{dc} & I^2_{dc} & \cdots & I^n_{dc} \end{bmatrix}^T
\]
Control of the DC voltage

- In a MTDC grid it is crucial to control the DC voltage at controllable levels both during normal operation and faulted conditions.
Control of the DC voltage

- The most common method of DC voltage control in a MTDC is the power based droop control

![Power based DC voltage droop control](image)

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The image illustrates the power based DC voltage droop control mechanism. The control system involves a DC Voltage Droop Controller that adjusts the power based on the difference in the actual and reference DC voltages. The equation for the droop control is shown as:

\[ \Delta P_{dc\_droop} = k_p \cdot (U_{dc0} - U_{dc}) + k_{i-p} \cdot \frac{1}{s} \int_{i_{d\_min}}^{i_{d\_max}} i_d \, dt \]

Where:
- \( U_{dc0} \) is the reference DC voltage.
- \( U_{dc} \) is the actual DC voltage.
- \( k_p \) is the power droop coefficient.
- \( k_{i-p} \) is the integral droop coefficient.
- \( i_d \) is the active current component of the VSC-HVDC.
- \( i_{d\_min}, i_{d\_max} \) are the minimum and maximum limits of the active current.

Inverter and Rectifier diagrams are also provided to illustrate the power flow and voltage control mechanisms in a MTDC system.
Test System: Results

- IEEE 39-bus test system in PSS/E
- Quasi-steady state model of the converter
- Standard type 4 model of wind turbines
- Standard 6\textsuperscript{th} order generator model with control

convensional generation = 5202.4 MW
onshore wind generation = 1600 MW
offshore wind generation = 800 MW
Total load = 7467.2 MW
Test System: Results

Radial connection

AC Terminal Voltage

DC Terminal Voltage

Converter Active Power

Onshore Converters DC Chopper
Test System: Results

Effect of the fault in the MTDC connected remote AC system

Converter Active Power

DC Terminal Voltage

Onshore Converters DC Chopper

G1002- Rotor angle deviation

Meshed DC grid
Radial DC grid
L13, L15, L25, L24, L34 = 100km
L16, L26 = 20km
L56, L46, L63 = 100km

IEEPE Power & Energy Society

IEEE
Test System: Results

Sensitivity of the DC voltage droop control parameters (radial connection)

\[ \text{Slope} = \frac{1}{K_p} \]

\[ U_{dc} \]

\[ P^A \]

\[ P^B \]

Converter Active Power VSC 301

Dissipated Power chopper 301

Converter Active Power VSC 302

Dissipated Power chopper 302

Converter Active Power VSC 303

Dissipated Power chopper 303

Deviation from st.st valie of rotor angle for G1002
Test System: Results

Sensitivity of the DC grid topology (meshed and radial MTDC)

AC Terminal Voltage - VSC 301

Active Power - VSC 302

Active Power - VSC 301

Active Power - VSC 303

Angle deviation from steady state of generators in Seven Generator System

G1001 - Meshed MTDC
G1001 - Radial MTDC

G1002 - Meshed MTDC
G1002 - Radial MTDC

Sensitivity of the DC grid topology (meshed and radial MTDC)
Summary

- Under AC side disturbances it is more the DC voltage droop control parameters which influence the AC/DC system interactions and less the topology of the MTDC grid itself.
- The higher is the proportional gain of the DC voltage droop controller, the larger is the active power overshoot that appears and the disturbance added to the asynchronously HVDC connected power system.
- There is a trade-off between the choice of the DC voltage droop controller and the Chopper in terms of power dissipated.
- In the case of ancillary services provided by the MTDC grid, the interactions between the DC voltage droop controller and the dedicated control loops should be extensively studied.
Thank you!!
References

